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EARLY FINDINGS FROM PIONEER VENUS

Early scientific findings by Pioneer Venus 1 and 2 include new information on the formation of the inner planets, an explanation for the heat which creates Venus' hell-like atmosphere and surface, and observation of "mysterious chemical fires" on the planet's surface.

Pioneer Venus 1, an orbiter, and the five atmospheric probes which comprised Pioneer Venus 2, reached cloud-covered Venus on Dec. 5 and 9, 1978.

The instrument-laden probes descended through the Venusian atmosphere to the surface, while the orbiter began an eight-month orbit of the planet, making measurements and taking pictures.

Scientists think the findings from Pioneer Venus about the Venus weather machine may help us understand the forces that drive the weather on Earth.

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Although much more analysis is needed, early Pioneer findings seem to provide new information about the formative years of the inner planets, Mercury, Venus, Earth, and Mars--and at what period the Sun ignited during these building processes.

Pioneer results also suggest that Venus' atmosphere circulates in large-scale global motions.

Other major findings include:

- The planet's searing atmosphere and surface heat now seem quite certainly to be due to a "runaway greenhouse effect."

- Venus' clouds come in three well-defined, distinct layers, and seem to result from a vigorous cycle of sulfur-hydrogen-oxygen reactions. Spacecraft instruments also found that the clouds are composed mostly of oxygen, water vapor and sulfur dioxide.

- Data from the orbiter's first radar map suggests that Venus' topography could be similar to Earth's, with high mountain-like features and extensive relatively flat areas. The Pioneer Day Probe also showed the presen e of fine dust on the surface at its landing site in the southern hemisphere. This dust took about three minutes to settle after impact of the 90-kilogram (200-pound) probe at 35 kilometers per hour (22 miles per hour). The Day Probe survived for 67 minutes after landing.

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- Starting at 13 km (8 mi.) altitude, the two night-side probes saw an unexpected glow increasing as the probes descended. Mass spectrometer evidence for various sulfur compounds near the surface suggests that the mysterious glow could come from "chemical fires" on the surface or in the very hot and dense lower atmosphere near the surface. The "fires" would be fueled by reactions involving the sulfur compounds. Experimenters are considering another possibility--that the glow resulted from the heated or electrically charged surfaces of the probe craft themselves.

- The solar wind interacts with the Venusian atmosphere several times more strongly than expected. Unlike solar wind interaction on Earth, three key upper atmosphere regions were discovered to almost coincide. They are the turbopause, where atmospheric mixing begins; the region of maximum ion density; and the base of the exosphere (the region where gases escape the planet to space).

- The Pioneer Venus spacecraft have thus far identified 10 chemical constituents of the atmosphere and 10 ions in the ionosphere of Venus.

• Composition of the planet's atmosphere appears to be as follows: about 97 per cent carbon dioxide, 1-3 per cent nitrogen, 250 parts per million (ppm) helium, 6-250 ppm neon, and 20-200 ppm argon. Other constituents measured below the cloud layer were water vapor 0.1 to 0.4 per cent, sulfur dioxide 240 ppm, and oxygen 60 ppm. There is indirect evidence that sulfuric acid and elemental sulfur particles also are found in the clouds. Further data analysis is expected to turn up additional sulfur compounds as well as other constituents.

Primordial Argon and Neon and Planet Formation

Pioneer found several hundred times more primordial argon and neon on Venus than on Earth. Mars, on the other hand, has far smaller amounts of these two primordial gases than has the Earth.

The argon/neon findings challenge most theories of Solar System formation, which propose that the Sun and planets formed at about the same time, with the planets forming from a gas cloud surrounding the Sun and composed of the same elements as the Sun.

The inner planets (Mercury, Venus, Earth, and Mars) are believed to be small and rocky because the Sun either swept away the light constituents (hydrogen, helium, argon, neon) by a more powerful solar wind than today's, or solar tidal effects may have pulled the light constituents into the young Sun. The other gas giants like Jupiter and Saturn appear to have kept their light gases. Jupiter, for example, is believed to consist of approximately the same mix of materials as the Sun.

Prior to Pioneer Venus, the generally accepted theory was that the volatile elements present in the atmospheres of Mars, Earth, and Venus were originally trapped in the material that ultimately formed those planets, and that these elements were subsequently degassed from each planet's interior to form its atmosphere. It also was generally assumed that the original solar gas and dust cloud was hot in the center and much cooler farther out at the time when the rare gases and other volatile elements were being trapped in the pre-planetary material. If this were correct, the abundance of rare gases should be lower on planets closer to the center of the Solar System than on planets farther out. However, the Pioneer data showed that the observed abundance pattern is the opposite.

These new results may mean that the temperature distribution in the early Solar System at the time the volatiles were trapped, was different than generally assumed.

If the entire gas cloud, which later formed the Sun and the planets, was evenly heated, then concentrations of light gases and other materials would increase going in toward the center due to gravity. These gases could then have been absorbed on dust grains in the gas cloud and the abundance of gases would be highest where the pressure was highest, that is in regions closer to the center of the nebula. In turn, as the dust consolidated into rock, the gases would have become trapped inside either large rocky masses which later formed the inner planets or inside the completely formed planets before the Sun heated up.

The fact that neon and argon are found in about the same proportions on Venus and Earth further strengthens the idea of a more uniform process and steady increase in density of all materials going toward the Sun.

While much more analysis is needed, these findings seem to begin to explain some of the mechanisms in the formation of the Solar System and planets.

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"Greenhouse" Heat Theory Strengthened

The intense Venus heat now seems to be explained by a massive "greenhouse" mechanism instead of by the competing theory of heat circulation from the top of the atmosphere down. In the greenhouse effect, solar radiation enters the atmosphere relatively easily but is reradiated to space as heat only with great difficulty. The trapped radiation heats up the planet and its atmosphere.

Of Venus' total incoming sunlight, about 75 per cent is reflected back to space by the Venus clouds and dense atmosphere. Of the remaining 25 per cent that penetrates Venus, about 60 per cent is absorbed in clouds, 15 per cent in the atmosphere above the clouds, 15 per cent in the lower atmosphere, and 10 per cent at the surface.

As this absorbed solar energy attempts to leave the surface and atmosphere as heat radiation, two materials, identified by Pioneer Venus, hold the heat in the atmosphere. Until now, the dense (97 per cent) carbon dioxide atmosphere was known to trap much of the heat, but not enough to account for the searing Venus surface temperatures, 455 degrees Celsius (850 degrees Fahrenheit).

The somewhat surprising finding is that 0.1 to 0.4 per cent water vapor content of the atmosphere provides the second very strong heat trap. Finally, it is now believed that the large solid and liquid sulfur particles in the cloud layers contribute to putting a lid on the Venusian pressure cooker, holding in still more heat.

Venus Cloud Profile

The Venus cloud layers have a total thickness of about 20 km (12 mi.). There are three distinct cloud layers.

The top layer of clouds is about 14 km (9 mi.) thick, from 70-56 km (43-35 mi.) altitude. This layer is made up of 1-2-micron diameter particles which seem to be sulfuric acid with about 300 particles per cubic centimeter. Temperature of this layer is around 13°C (55°F.).

The second cloud layer is 6 km (4 mi.) thick, from 56-49.5 km (35-31 mi.). This layer appears to be made up of the 1-2-micron sulfuric acid particles, 4-micron particles which appear to be some form of liquid, and 10-15-micron particles which could be solid elemental sulfur. This cloud layer has about 100 particles per cubic centimeter. Its temperature is about 20°C (68°F.).

The bottom layer is the only layer opaque enough to be like most Earth cloud structures. Two km (3 mi.) thick, the layer lies between 49.5-47.5 km (31-30 mi.) altitude. It is the densest of the three layers with 400 particles per cubic centimeter and has but a few 1-2-micron sulfuric acid particles and many large 10-15-micron particles of what might be both liquid and solid sulfur. Temperature in this bottom layer is about 202°C (395°F.).

Near the bottom of this dense sulfur cloud, at about 47.5 km (29 mi.)altitude, the temperature appears to be near the melting point of sulfur. A "pre-cloud" layer of droplets similar in composition to the top cloud layer--with 300 particles per cubic centimeter--appears at this level for a few hundred meters. A faint haze then appears below, made up of submicron particles which might be sulfuric acid. These tiny particles are present in densities of about 20 particles per cubic centimeter. They thin out to about two particles per cubic centimeter at the bottom of the haze layer, at about 30 km (19 mi.).

From about 30 km (19 mi.) down to the surface, the atmosphere is free of particles, according to the data.

Cloud Circulation Process

Sulfuric acid droplets plus liquid and solid sulfur appear to drift slowly down from the clouds, falling to the hotter, lower altitude, about 47.5 km (29 mi.). There this material vaporizes and splits up, forming a kind of "chemical stew." The basic building blocks of the Venus cloud particles--water vapor, sulfur dioxide and molecular oxygen--have so far been measured in this region.

In addition, a variety of sulfur compounds are beleived to be formed. This sulfurous "soup" then appears to be recirculated back up to the cloud layers where it is re-formed into sulfuric acid and sulfur, perhaps by reactions involving incoming solar ultraviolet radiation.

The presence of free oxygen and water vapor in Venus' lower atmosphere and its absence in significant amounts above the clouds suggest that the reactions in the clouds are so vigorous that they remove the free oxygen and water vapor and prevent them from passing through the clouds.

Elemental sulfur is not found above 56 km (35 mi.). This is high enough for ultraviolet light to penetrate through the thin upper clouds and be absorbed by sulfur. (Prominent dark cloud markings in ultraviolet pictures of Venus seem to be due to sulfur absorption.)

First Surface Mapping

The first preliminary scans by the orbiter's radar mapper showed that in a previously unexplored 1900-km (1200-mi.)-strip on Venus' surface much of the terrain appears relatively flat, similar to Earth's surface and dissimilar to the rough, cratered terrain of Mars and the Moon.

An exception to the relatively smooth surface on Venus was a drop in altitude of 10,000 feet over one area 120 km (75 mi.) long. This is comparable to the drop between the crest of the Front Range of the Rocky Mountains near Denver to a spot out in the Great Plains to the east. More scans by the orbiter will be needed for any kind of comprehensive picture of Venus' terrain.

Cloud Tops and Atmospheric Circulation

Detailed findings by the orbiter's infrared radiometer about Venus' upper atmosphere and cloud tops included the fact that the temperatures on the day side of Venus are very close to those on the night side. Nephelometer findings also show that cloud tops are close to the same heights on both day and night sides.

Other radiometer findings at the poles appear to confirm theories of a downward-moving polar vortex.

Surprisingly, the belt of atmosphere above the cloud tops at the poles is about 10°C (21°F.) hotter than at the equator. This contradicts earlier findings that the poles were 10°C (21°F.) cooler than the equator.

At about 70° latitude, a wide ring of colder and higher clouds circles the poles Temperature of these clouds is about -58°C (-73°F.) -- about 50°C colder than the hottest polar cloud top temperature. In the "polar hole" believed created by the vortex, cloud tops seem about 10 km (6 mi.) lower than surrounding cloud tops. Cloud temperature in the hole is about 30°C higher than average cloud top temperatures. Both the atmosphere and the clouds get warmer going down to the lower altitudes in the polar hole.

Finally, there appears to be a haze layer about 10 km (6 mi.) above the clouds, surrounding the planet but thicker over the polar regions. The polar haze appears to be opaque to the longer infrared wavelengths. The opaque material has characteristics similar to water vapor or ice crystals, as in Earth's cirrus clouds.

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Upper Atmosphere

In upper atmosphere findings, the sensible atmosphere of Venus begins at 250 km (155 mi.) altitude and has a density of 10^{-15} grams/cc. It reaches a density of 10^{-10} grams/cc at 125 km (78 mi.). The turbopause (where atmospheric-mixing replaces atmosphere layered by weight) begins at an altitude of 144 km (90 mi.). Temperature at 250 km (155 mi.) is 27°C (80°F.). At 100 km (62 mi.) it drops to -93°C (-136°F.) and near the surface rises again to 447°C (836°F.).

Above the turbopause, the Pioneer craft thus far have found hydrogen, oxygen, carbon dioxide, argon, helium, nitrogen, and carbon monoxide.

The Venus Atmosphere and Clouds -- A Probe's-Eye View

If passengers could be placed on the four Pioneer Venus probes as they descended through the atmosphere, this is what they would probably experience:

Riding the Day Probe from space down into the Venus atmosphere, a passenger would first cross the bow shock wave in the one-million°C (1,800,000°F.) solar wind at about 7000 km (4650 mi.) from the Venusian surface.

He then would pass through the turbulent transition region before reaching the top of the ionosphere at about 400 km (240 mi.) altitude.

Moving down through the tenuous upper atmosphere, a passenger would see far below yellowish surfurous clouds, which, along with the dense atmosphere, reflect 75 per cent of the sunlight away from the planet. As the probe passes the turbopause at 144 km (90 mi.), the clouds appear 76 km (47 mi.) below as a dense, smog-like haze.

Venus' cloud region begins at about 70 km (43 mi.) altitude and extends for 20 km (12 mi.) to 47.5 km (30 mi.) altitude.

The Sun begins to grow dim at about 66 km (41 mi.) from the surface. By 63 km (39 mi.) altitude, the Sun is no longer a visible disc behind the diffuse yellow cloud layer made up of tiny sulfuric acid particles. Visibility through the high Venusian smog at that height is about 6 km (4 mi.) and the temperature is 13°C (55°F.). The atmospheric pressure is about one-half that at Earth's surface.

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At 49.5 km (31 mi.) altitude in a mild temperature of 20°C (68°F), a passenger could see about a mile. After passing a short, clear space in the hazy cloud layers, the probe enters the bottom layer where the atmospheric pressure is about equal to that at the Earth's surface. The temperature rises to about 202°C (395°F.) Here the sulfur clouds are densest, with a few of the 1-micron sulfuric acid particles and many large 10-15-micron particles of sulfur. These are the only Venusian clouds dense enough to look like cloud structures on Earth. All other Venusian "clouds" are made up of particles so dispersed that they look more like haze.

Beneath this dense sulfur cloud, there is a second clear space and a "pre-cloud" layer of a few hundred meters, which is similar to the top cloud layer. The probe passenger would see a faint haze at about 47.5 km (29 mi.) altitude.

As the haze clears away at about 30 km (19 mi.), the atmosphere becomes clear of particles. Visibility in the dispersed light coming through the yellowish clouds is 80 km (50 mi.). Illumination is comparable to a bright cloudy day on Earth. Temperature at 30 km (19 mi.) is about 310°C (590°F.).

At 20 km (12 mi.) altitude, where the temperature is 380°C (716°F.), the light becomes redder. Because of light scattered by Venus' thick atmosphere, visibility is down to around 20 km (12 mi.). At 10 km (6 mi.) altitude, the light is quite red and horizontal visibiltiy is only 12 km (7 mi.). Illumination is gloomy and the temperature is a scorching 410°C (770°F.).

At about 7 km (4 mi.) altitude, some surface features begin to become visible in the red murk below.

Landing on the surface, where the temperature is about 453°C (847°F.), and only 10 per cent of non-reflected sunlight is reaching the ground, the passenger cannot tell where the Sun is located in the sky. Illumination is red with much refraction and distortion of landmarks. Only the longest red wavelengths travel any distance through this atmosphere which is 91 times as dense as the atmosphere at the Earth's surface. Visibility in this dense carbon dioxide atmosphere is about 3 km (1.5 mi.). Overhead illumination is still comparable to a gloomy day on Earth.

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Where Is the Venus Water?

Other Pioneer Venus findings bear on what happened to Venus' water vapor (if the planet ever had any) and on comparisons with the Earth's atmosphere.

Measurements showed that the Venus atmosphere has about the same amount of nitrogen as Earth's atmosphere.

Both planets have roughly equal amounts of carbon dioxide, but most of Earth's is locked in carbonate rocks. Venus' carbon dioxide makes up 97 per cent of its atmosphere.

The findings of .1-.4 per cent of water vapor and 60 parts per million (ppm) free oxygen will help tell us whether Venus originally had abundant water and lost it--or never had much water. Many scientists think Venus' primordial water circulated to the top of the atmosphere where solar ultraviolet broke it down into hydrogen and oxygen. As the lightest element, hydrogen then escaped to space. (The Pioneer measurements show such low hydrogen-escape rates today that water loss, if it did happen, has long since ceased.) If massive water loss did occur this way, where is the left-over oxygen?

If Venus has an Earth-like geology, as the early Pioneer results suggest, the oxygen could be locked up in the planet's crustal rocks, as carbon dioxide is on Earth. An Earth-like geology would mean that much of the surface rock has been overturned to deep levels by crustal folding and other movements over the past three billion years.

The Solar System is calculated to be 4.5 billion years old. This allows 1.5 billion years for water breakdown and hydrogen loss, plus three billion years for the left-over oxygen to combine with surface rocks. Quantity calculations for oxygen reactions such as conversion of ferrous to ferric iron show the oxygen could be locked up in Venus' rocks.

Solar Wind Interactions

Experimenters found the interaction of the solar wind with the planet's ionosphere was several times more powerful than expected. The planet's bow shock wave in the solar wind was very strong with powerful upstream plasma waves in front of it, out a distance of several planet diameters. Since Venus has little or no magnetic field, the solar wind is not swept away from the planet as it is at the Earth, but interacts directly with the top of the Venus atmosphere and ionosphere.

Earth's bow shock wave is typically 65,000 km (40,000 mi.) out at the nose of the shock. Venus' bow shock was found to lie typically eight times closer, at 8,000 km (4,200 mi.) out. Top of the Venus ionosphere appears to average about 400 km (240 mi.) out, while the sensible atmosphere begins at 250 km (150 mi.).

The region between the bow shock and the top of the ionosphere is typically about 7,500 km (4,650 mi.) wide at the nose of the shock. Both the solar plasma and the magnetic field in this region were very turbulent and very high in temperature, about 1 million °C (1.8 million °F) or many times the comparable temperatures in the region near Earth. At the ionosphere's top, experimenters found relatively strong magnetic fields. The Venus ionosphere also was very responsive to solar wind pressure. The pressure deformed the ionosphere, moved it in and out, or both.

Unexpectedly, the solar wind is held off at least as strongly by Venus' ionosphere as it is by the Earth's magnetosphere. It was not believed that Venus' ionosphere alone, with little or no planetary magnetic field to help, could do the job as well. (The holding off is actually done by the magnetic field induced in Venus' ionosphere by the solar wind motion relative to it.)

Interaction Mechanisms

Differences have been found between Venus' and Earth's solar-wind interactions. At Venus, the wind confines the ionosphere below a well-defined boundary, the ionopause. The Earth has no such boundary. Pioneer observed varying heights for the ionopause with solar wind changes.

During the first week of orbit, wind speed slowly fell from 500 to 250 km/s (from one million to a half million mph). In response, the ionopause slowly rose from 250 to over 1,500 km (155 to 930 mi.). When a solar flare raised solar wind speed to 600 km/s (1.3 million mph), it increased its pressure on the ionosphere 10 times. The ionopause was crushed back down to 250 km (165 mi.).

Some solar wind ions seem to penetrate below the ionopause, heating the electron temperature to 5,000°K (8,500°F). It would otherwise be only 1,000°K (1,300°F).

Structures of the upper atmosphere and ionosphere are dominated by three important heights, all measured for the first time by the Pioneer Bus.

The turbopause at 144 km (90 mi.) is the boundary above which gases separate by density to form layers of different compositions. Below the turbopause, mixing stirs all the gases uniformly together. The maximum ion density of the ionosphere is also at 145 km (90 mi.). Ion density falls off very rapidly below this altitude. Here, the most abundant ions are O_2^+ and CO_2^+, but O^+ takes over from shortly above ion maximum all the way to the top of the ionosphere.

The exobase, the bottom of the exosphere, the region from which gas molecules escape into space, is at 160 km (100 mi.). Thus, turbopause, ion maximum, and exobase heights almost coincide. By contrast, on Earth, these heights are at 100, 300, and 550 km (60, 120, and 350 mi.), respectively.

Venus' Ionosphere

Venus has an ionosphere on its night side. Previously this was a mystery because solar ultraviolet and X-rays do not reach the night side to form an ionosphere during Venus' 58-Earth-day-long nights. Pioneer findings of extremely long-lived metal ions of meteoritic origin (iron and magnesium) may be a discovery that explains Venus' night ionosphere.

Ions found in the ionosphere were molecular oxygen, atomic oxygen, carbon dioxide, carbon monoxide, atomic nitrogen, carbon hydrogen, helium, iron and magnesium.

Succeeding months should bring more Pioneer findings. Some will be: calculation of Venus' winds along all four probe flight paths, with accuracy "fine-tuned" by the 67-minute survival of the Day Probe on Venus' surface. Others should be further atmosphere composition analysis and composition analysis of a cloud droplet that entered the mass spectrometer on the Large Probe.

The orbiter will be returning pictures and other data on the planet and its interior for a year.

The Pioneer spacecraft are managed by NASA's Ames Research Center, Mountain View, Calif. The spacecraft were built by the Hughes Aircraft Co., El Segundo, Calif.

First scientific papers on Pioneer Venus findings will appear in the February 15 issue of Science.

(This information also being released by the NASA Ames Research Center, Moffett Field, Calif.)

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